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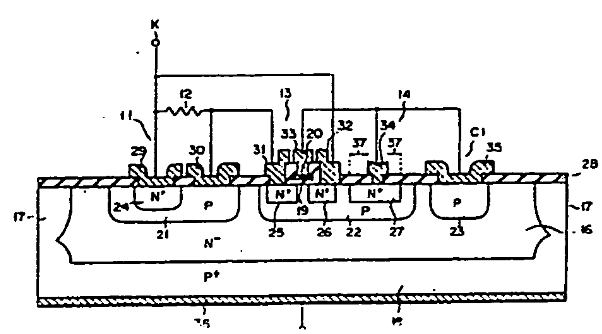
(54) OPTICAL SEMICONDUCTOR DEVICE HAVING A ZERO-CROSSING FUNCTION.

(57) An optical semiconductor device having a zero-crossing function is constituted by a light trigger thyristor (11) controlled by a light trigger signal, a MOSFET (13) and a Zener diode (14) that are formed in the same semiconductor substrate (16) in a monolithic form. A current path between the source and the drain of the MOSFET (13) is connected between the gate and the cathode of the light trigger thyristor (11). The MOSFET (13) controls the gate sensitivity of the light trigger thyristor (11). The Zener diode (14) is connected at its anode to the cathode of the light trigger thyristor (11) and is connected at its cathode to the gate of the MOSFET (13). The Zener diode (14) protects the gate oxide film (19) of the MOSFET (13) from the insulation breakdown. The Zener diode (14) is provided with a [illegible] photodiode when it is irradiated with the light trigger signal. Upon irradiation with the light trigger signal, a photocurrent generated in the Zener diode (14) flows from the gate of MOSFET (I3) to the cathode of the light trigger thyristor (11). This suppresses the rise of gate voltage of the MOSFET (14).



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gate and cathode K of the photo-trigger thyristor 11. A current path between the source and drain of a MOSFET 13 is connected in parallel to the resistor 12, or is connected between the gate and cathode K of the thyristor 11. The MOSFET 13 has its back gate connected to the cathode K. A Zener diode 14 has its anode connected to the cathode K and its cathode connected to the gate of the MOSFET 13. A voltage pickup circuit 15 comprising capacitors C1 and C2 serves to apply to the gate of the MOSFET 13 a gate bias voltage corresponding to a voltage applied between the anode A and cathode K of the thyristor 11, and this function is equivalently represented by the capacitors C1 and C2. The capacitor C1 has its one electrode connected to the anode A of the thyristor 11, and the other electrode connected to one electrode of the capacitor C2 and the gate of the MOSFET 13. The other electrode of the capacitor C2 is connected to the cathode K. The capacitor C1 is the capacitance of a PN junction formed to pick up a voltage between the anode A and cathode K of the thyristor 11. The capacitor C2 is the combined capacitance of the capacitance of the depletion layer of the PN junction of the Zener diode 14 and the gate capacitance of the MOSFET 13, i.e., it equivalently represents a parasitic capacitance.

A gate current generated by an optical trigger signal supplied to the gate of the photo-trigger thyristor 11 has a smaller value as compared with the gate trigger current of an ordinary thyristor, so that the thyristor 11 is required to have a high gate sensitivity. With the photo-trigger thyristor 11 designed to have a high gate sensitivity, however, the dV/dt withstandability decreases. Like this, the gate sensitivity and the dV/dt withstandability have a trade-off relation. Accordingly, the MOSFET 13 for controlling the gate sensitivity is provided to improve the relation between the gate sensitivity and the dV/dt

The zero-cross type thyristor has the following two main effects. First, in performing the ON/OFF control of AC power of an commercially available frequency by a thyristor which is not of a zero-cross type, when the thyristor is turned on at the phase of a high value AC voltage (depending on a load), noise generally occurs due to by a rush current or a transient voltage. This would cause a malfunction of an LSI circuit, an IC logic circuit, etc. provided near the thyristor or give an electromagnetic trouble, such as a radio or TV noise problem to electronic appliances. The zero-cross circuit has an effect to significantly suppress the electromagnetic trouble. The second effect is such that with a thyristor designed to have a high gate sensitivity, the high gate sensitivity is given only when the AC voltage VAK is at the phase of the zero-cross portion, and the thyristor has a so-called cathode-emitter short-circuit structure at other phases to thereby significantly reduce the gate sensitivity. As a result, the dV/dt withstandability is improved.

The Zener diode 14 is provided to protect the gate insulating film of the MOSFET 13. This is because the thickness of the gate insulating film of the MOSFET 13 is determined mainly by the desired threshold voltage Vth and cannot be set sufficiently thick to prevent the dielectric breakdown. In other words, the diode 14 having a Zener voltage smaller than the dielectric breakdown voltage of the gate insulating film is provided between the gate of the MOSFET 13 and the cathode K of the thyristor 11, so that when an abnormal voltage exceeding the Zener voltage is applied, it is broken down to be led to the cathode K.

The output voltage of the voltage pickup circuit 15 (voltage at the common node between the capacitors C1 and C2) is substantially equal to the reciprocal ratio of the capacitors C1 and C2 with respect to the anode-cathode voltage VAK of the thyristor 11. When the

the photo-trigger thyristor to be turned on at the zero-cross portion, i.e., the dV/dt ON characteristic. It is desirable that the value of the dV/dt ON characteristic be as large as possible, and the voltage VW is wanted to be larger. In contrast, in order to improve the dV/dt withstandability of the photo-trigger thyristor, it is desirable to turn on the MOSFET by as small a voltage VAK as possible with a contradictory request to make the value of the dV/dt ON characteristic smaller. Conventionally, however, it is difficult to satisfy both a large value of the dV/dt ON characteristic and a high dV/dt withstandability.

Accordingly, it is an object of the present invention to provide a photo-semiconductor device with a structure which can improve the dV/dt ON characteristic without reducing the dV/dt withstandability in a photo-trigger thyristor having a zero-cross circuit using a MOSFET.

Disclosure of the Invention

A photo-semiconductor device of the present invention having a zero-cross function in which a photo-semiconductor element whose ON/OFF state is controlled by an optical trigger signal, a MOSFET having a current path between its source and drain connected between a control electrode and a first main electrode of the photo-semiconductor element and having a gate applied with a bias voltage corresponding to a voltage applied between the first main electrode and a second main electrode of the photo-semiconductor element to thereby serve as a zero-cross circuit, and a Zener diode, having an anode connected to the first electrode of the photo-semiconductor element and a cathode connected to the gate electrode of the MOSFET, for protecting the MOSFET are formed in monolithic manner, characterized in that the Zener diode has a light receiving portion for receiving the optical trigger signal so that when the optical trigger signal is

device of the present invention;

Fig. 3A is an enlarged pattern plan view illustrating the structure of a Zener diode in the photo-semiconductor device in Fig. 2;

Fig. 3B is a cross section of the structure along the X-X' line in Fig. 3A;

Fig. 4A is a pattern plan view illustrating another structure of the Zener diode in the photo-semiconductor device shown in Fig. 2;

Fig. 4B is a cross section of the structure along the Y-Y' line in Fig. 4A;

Fig. 5 is a cross section of the photo-semiconductor device shown in Fig. 2 for explaining its action;

Fig. 6 is a cross section exemplifying the structure of the second embodiment of a photo-semiconductor device of the present invention; and

Fig. 7 is a cross section exemplifying the structure of the third embodiment of a photo-semiconductor device of the present invention.

Best Modes of Carrying Out the Invention

This invention will now be described referring to the accompanying drawings.

Fig. 2 illustrates the first embodiment of a photo-semiconductor device of the present invention, which has a zero-cross function. This photo-semiconductor device, basically represented by an equivalent circuit shown in Fig. 1, is a compound photo-trigger thyristor, which comprises a photo-trigger type thyristor 11, a MOSFET 13 for controlling the gate sensitivity of the thyristor 11, and a Zener diode 14 for protecting the gate insulating film of the MOSFET 13.

The outline of manufacturing processes of the device will now be given with an explanation of the structure thereof. First, a P type impurity is selectively introduced in an N^- type silicon substrate 16 with a specific resistance of approximately 40 $\Omega\cdot$cm

emitter region 24 with a diffusion depth of approximately 10 µm. This N^+ emitter region 24 becomes a cathode region for the photo-trigger thyristor 11. Then, an N type impurity is selectively ion-implanted in the surface region of the P-well region 22 to form an N^+ drain region 25 and an N^+ source region 26 of the MOSFET 13, and an N^+ impurity region 27 of the Zener diode 14, at predetermined intervals at a diffusion depth of about 5 µm. An oxide film 28 is formed on the whole major surface of the substrate 16, and contact holes for connecting all the electrodes are formed in the oxide film 28. Thereafter, a metal layer, such as an aluminum layer, which serves as an electrode, is vapor-deposited on the entire surface, and is subjected to patterning. As a result, a cathode electrode 29 and a gate electrode 30 of the photo-trigger thyristor 11, a drain electrode 31, a source electrode 32 and a gate electrode wiring 33 of the MOSFET 13, an electrode 34, and an electrode 35 of the voltage pickup section are formed. Likewise, an anode electrode 36 made of gold or the like is formed on the bottom substrate 16. The source electrode 32 is formed over the P-well region 22 and the source region 26 to contact them. Further, the electrode 34 of the Zener diode 14 is formed on that portion of the oxide film 28 above the N^+ impurity region 27 in such a way as not fully cover the region 27. A regions 37, which is above the N^+ impurity region 27 and is not covered with the electrode 34, serves as a light receiving portion for receiving an optical trigger signal.

The anode electrode 36 of the thyristor 11 is connected to an anode terminal A, and the cathode electrode 29 to a cathode terminal K. A resister 12 is connected between the cathode electrode 29 and the gate electrode 30, and it is formed of a polysilicon layer formed on the substrate 16 via an insulation film. The drain electrode 31 of the MOSFET 13 is connected to one

to the Zener diode 14, which is the main characteristic of the present invention.

When the forward bias voltage VAK is applied between the anode terminal A and the cathode terminal K of the photo-trigger thyristor 16, a junction J1 between the P base region 21 and the N^- type substrate 16, a junction J2 between the P-well region 22 and the substrate 16, and a junction J3 between the P type impurity region 23 of the voltage pickup section and the substrate 16 are reverse-biased, so that depletion layers as indicated by broken lines are formed, as shown in Fig. 5. Since the N^+ impurity region 27 of the Zener diode 14 is at a positive potential with respect to the P-well region 22, due to combining of the capacitances by the depletion layer formed at the junction J3, a depletion layer is also formed at a junction J4 of the Zener diode 14. The electrode 35 of the voltage pickup section is electrically connected to the anode terminal A via the capacitance of the depletion layer at the junction J3, and to the cathode terminal K via the capacitances of the depletion layer at the junction J4 and the static capacitance or the like of the gate electrode 20 of the MOSFET 13 and the N^+ source region 25. If the voltage VAK between the anode terminal A and the cathode terminal K is low within the range of the zero-cross portion, the voltage VP of the electrode 35 of the voltage pickup section takes a value close to the voltage VAK, and increases in proportion to the voltage VAK. (The voltage VP is however saturated when the voltage VAK becomes large and the depletion layers of the junctions J2 and J3 become close to each other.)

When the trigger light is irradiated and received at the light receiving portion 37, a photoelectric current flows in the Zener diode 14 in the direction of the arrowhead from the N^+ impurity region 27 to the P-well region 22. This photoelectric current serves to leak the charges accumulated in the static capacitor

However, such a variation can be suppressed to the minimum by controlling the capacitances of the voltage pickup section and the electrode 20 of the MOSFET 13.

In the aforementioned first embodiment, the P type impurity region 22 is to supply the bias voltage corresponding to the voltage applied between the anode and the cathode of the thyristor 11, to the gate of the MOSFET 13. Alternately, an electrode 35 may be provided on the substrate 16 through an insulating film 38 as shown in Fig. 6. The same reference numerals as used in Fig. 2 are given to the identical structural elements in Fig. 6, and their detailed description will be omitted.

This structure can basically perform the same operation as the first embodiment and can provide the same effect.

Although the voltage pickup section is formed in the same semiconductor substrate in the first and second embodiments, a voltage dividing circuit, which comprises a static capacitor and divides the voltage between the anode and cathode of the thyristor 11, may instead be provided externally.

Further, although the foregoing description of the above embodiments has been given with reference to a photo-trigger thyristor as an example, this invention may be applied to other photo-semiconductor devices, such as a reverse-flow preventing, three-terminal thyristor and a triac, which have three or more PN junctions, and have two stable states, on and off, in at least one quadrant of the main voltage-current characteristic, as long as the switching the photo-semiconductor devices to the ON state from the OFF state can be executed an optical trigger signal.

Fig. 7 illustrates the cross-sectional structure of the third embodiment of a photo-semiconductor device according to the present invention as applied to a lateral photo-trigger triac. In this figure,

Likewise, a second PNPN structure (second photo-trigger thyristor 50-2) is formed by a P base region 53-2 formed in the major surface region of the N^- type silicon substrate 51, an N emitter region 57-2 selectively formed in this region 53-2, the substrate 51 as an N^- base region and a P emitter region 52-2. A second main electrode 61-2 is formed in an ohmic contact with the N emitter region 57-2 and the P emitter region 52-1 of the first thyristor 50-1. In a P-well region 54-2 are formed a second MOSFET 68-2 for controlling the gate sensitivity of the second photo-trigger thyristor 50-2, and a second Zener diode 69-2 for protecting the gate insulating film of this MOSFET 68-2. The second Zener diode 69-2 has a light receiving portion 70-2 for receiving an optical trigger signal. In the major surface region of the substrate 51 is formed a P type impurity region 55-2 as a voltage pickup section for applying a gate bias voltage to the second MOSFET 68-2. The N^+ source region 59-2 of the MOSFET 68-2 is connected to the N emitter layer 57-2 through the source electrode 64-2 and second main electrode 61-2. The N^+ drain region 58-2 of the MOSFET 68-2 is connected to the P base region 53-2 through the drain electrode 63-2 and the second gate electrode 62-2 of the photo-trigger triac 50. The first main electrode 61-2 and source electrode 64-2 are connected with a second main electrode terminal T2. A resistor 71-2 is connected between the source electrode 63-2 and the second main electrode terminal T2. The gate electrode wiring 72-2 of the MOSFET 68-2, the electrode 65-2 of the Zener diode 69-2 and the electrode 66-2 of the voltage pickup section are connected together.

The feature of this embodiment lies in that the light receiving portions 70-1 and 70-2 are respectively provided on the N^+ impurity regions 60-1 and 60-2 of the Zener diode of the photo-trigger triac. The operation and action are basically the same as those of the first

Claims:

1. A photo-semiconductor device having a zero-cross function in which a photo-semiconductor element whose ON/OFF state is controlled by an optical trigger signal, a MOSFET having a current path between its source and drain connected between a control electrode and a first main electrode of said photo-semiconductor element and having a gate applied with a bias voltage corresponding to a voltage applied between said first main electrode and a second main electrode of said photo-semiconductor element to thereby serve as a zero-cross circuit, and a Zener diode, having an anode connected to said first electrode of said photo-semiconductor element and a cathode connected to a gate electrode of said MOSFET, for protecting said MOSFET are formed in monolithic manner, characterized in that said Zener diode has a light receiving portion for receiving the optical trigger signal so that when the optical trigger signal is applied on said light receiving portion, said Zener diode serves as a photodiode and permits a photoelectric current generated by applying the optical trigger signal to flow through said first main electrode of said photo-semiconductor device from said gate of said MOSFET to thereby suppress build-up of the gate bias voltage of said MOSFET.

2. A photo-semiconductor device according to claim 1, wherein said photo-semiconductor element includes a photo-trigger thyristor.

3. A photo-semiconductor device according to claim 2, wherein said photo-trigger thyristor includes a semiconductor substrate of a first conductivity type, a first semiconductor region of a second conductivity type formed in a major surface region of said semiconductor substrate, a second semiconductor region of a first conductivity type formed in a surface region of said first semiconductor region and having a higher impurity

7. A photo-semiconductor device according to claim 1, further comprising bias means for applying a bias voltage corresponding to a voltage between said first and second main electrodes of said photo-semiconductor element.

8. A photo-semiconductor device according to claim 7, wherein said bias means includes an impurity region of a second conductivity type formed in a major surface region of a semiconductor substrate of a first conductivity type, and an electrode formed on said impurity region.

9. A photo-semiconductor device according to claim 7, wherein said bias means includes an insulating layer formed on a major surface of a semiconductor substrate of a first conductivity type and an electrode formed on said insulating layer.

10. A photo-semiconductor device according to claim 1, further comprising a load element connected between said control electrode and said first main electrode of said photo-semiconductor element.

11. A photo-semiconductor device according to claim 10, wherein said load element includes a resistor.

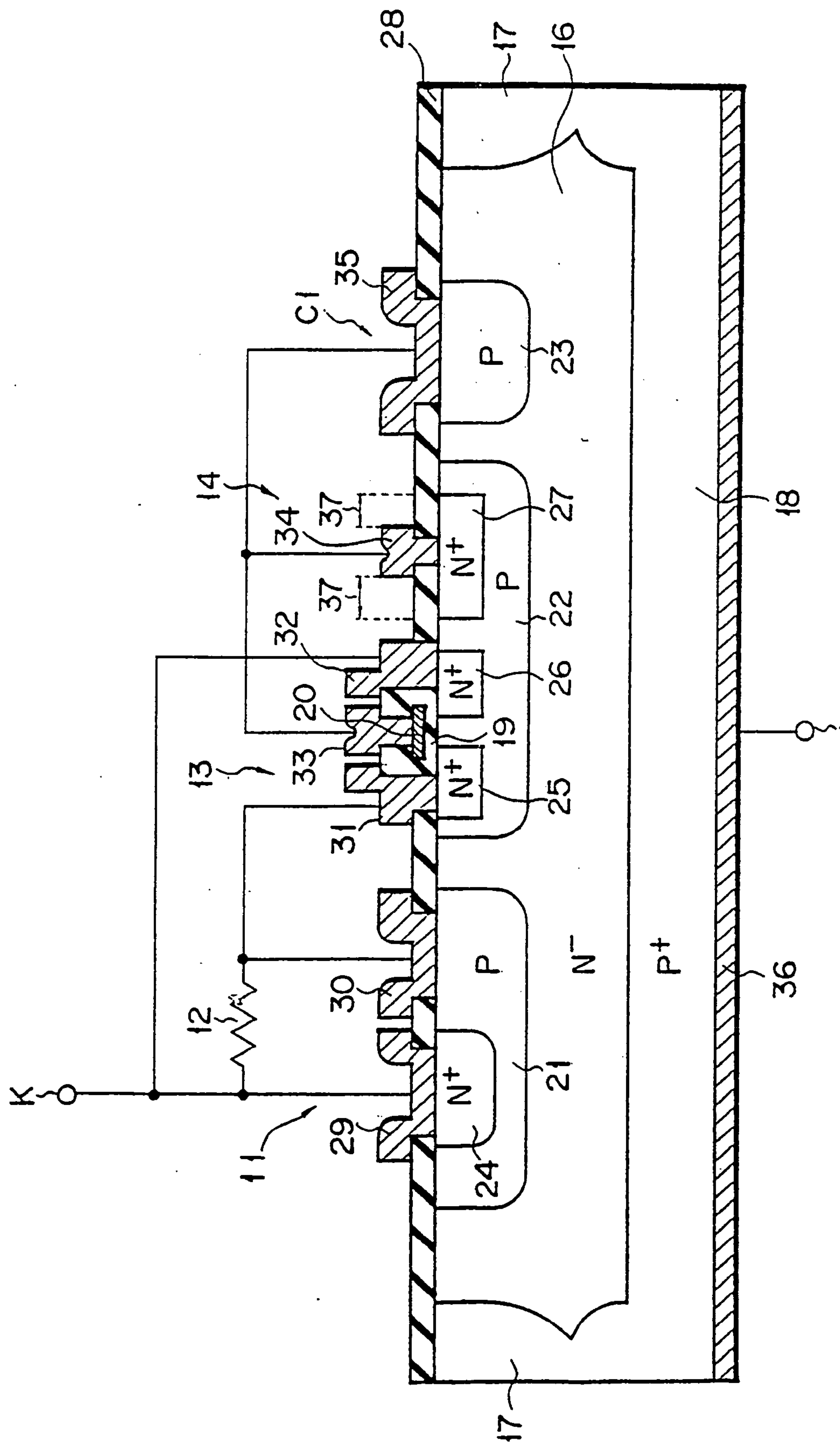
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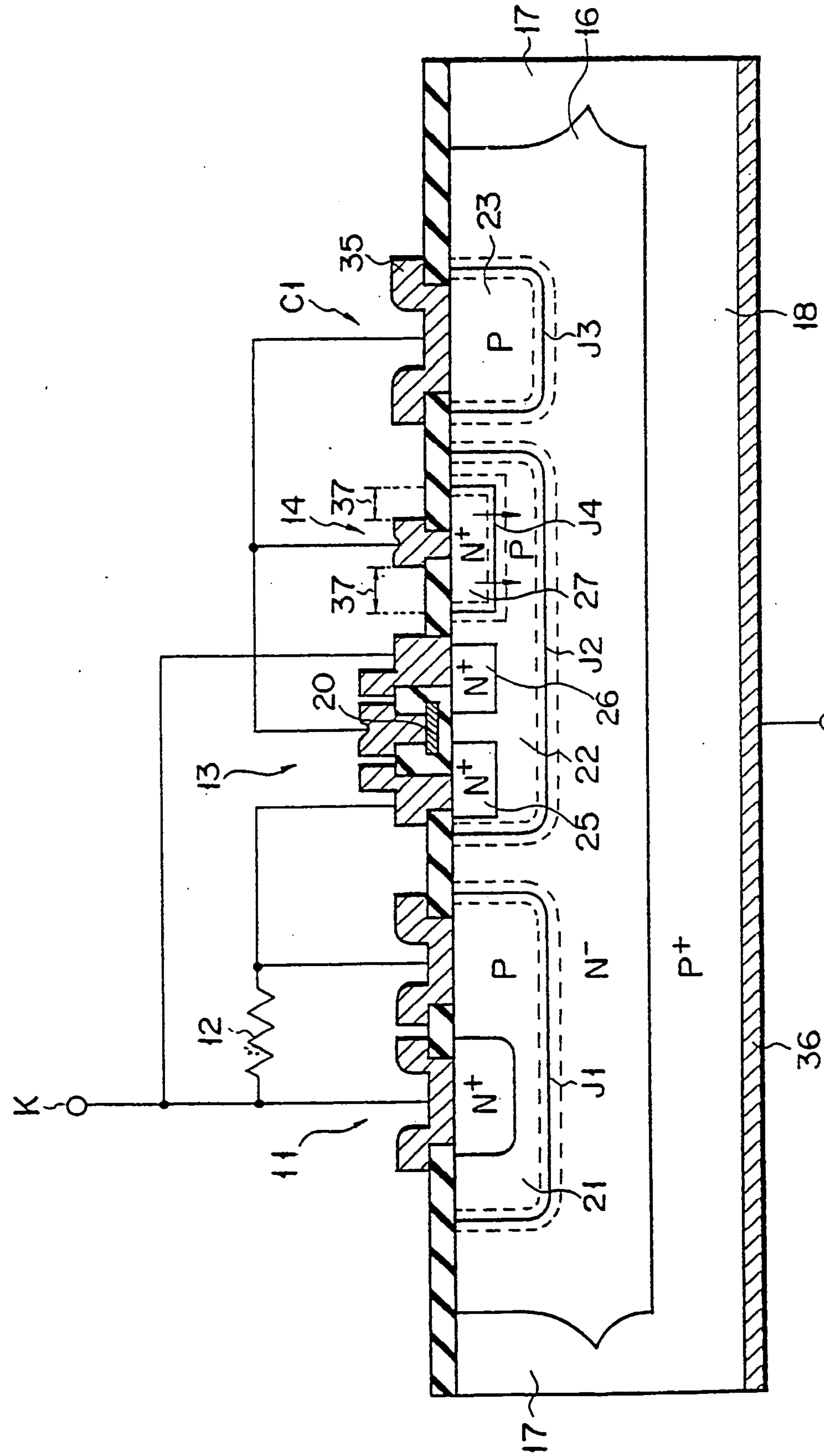
FIG. 2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17

FIG. 5

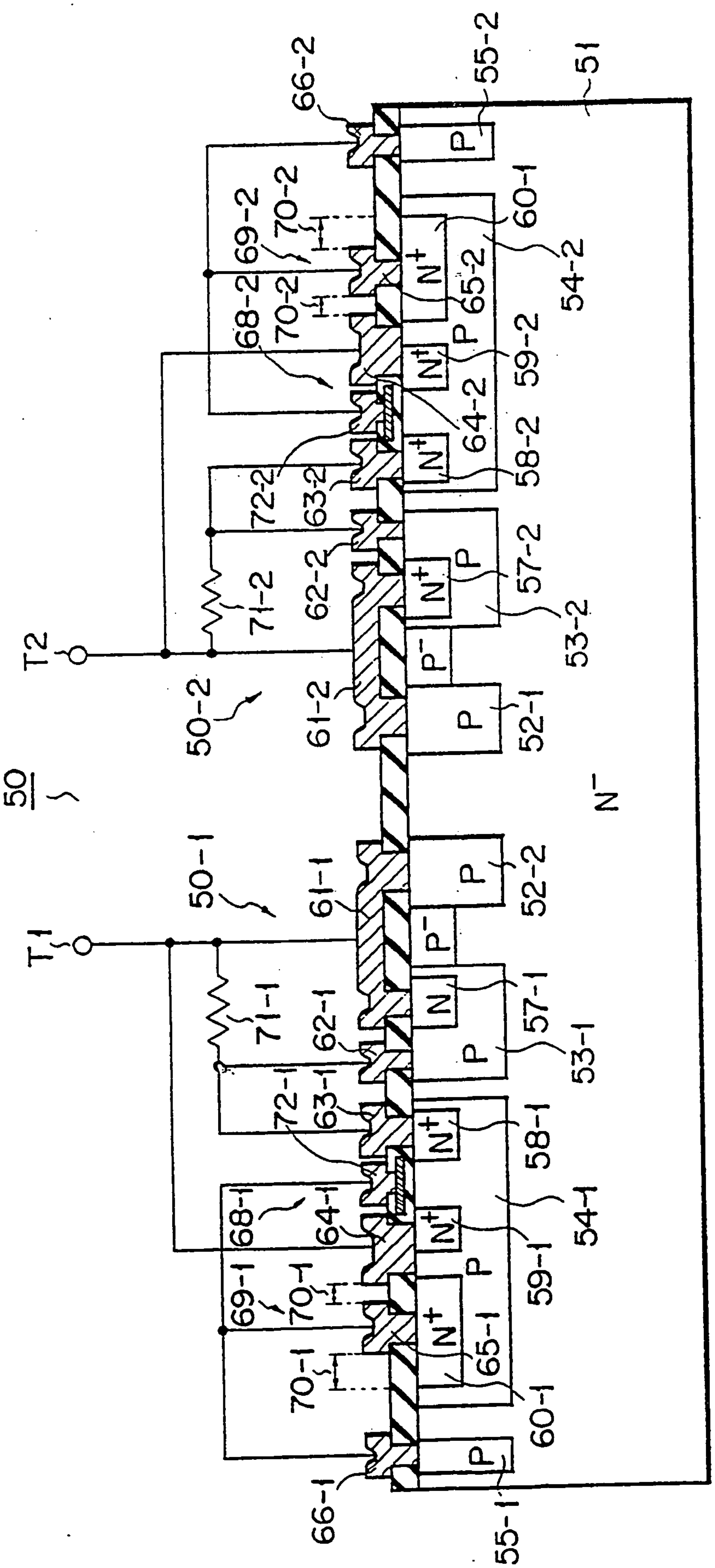
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FIG. 7